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EFFECTS OF RUBIDIUM VAPOR ON BAYARD-ALPERT IONIZATION GAGES AT PRESSURES LESS THAN 1×10⁻⁶ TORR

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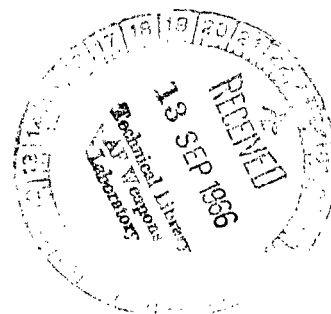
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SUMMARY

Measurements have been made on Bayard-Alpert ionization gages, operated in rubidium vapor over the pressure range of 10^{-9} to 10^{-6} torr. The effects of rubidium vapor on ionization gages were determined. Effects traceable to the condensable nature of rubidium vapor were noted. The ionization-gage sensitivity to rubidium was determined to be 9.1 times the nitrogen sensitivity of the gage, with a probable error of 14 percent.

In addition, the variation of gage sensitivity with grid voltage was determined for both cesium and rubidium.

INTRODUCTION

In a previous report (ref. 1) the sensitivity of a Bayard-Alpert ionization gage to cesium vapor was determined to be 13.7 times the nitrogen sensitivity. However, this sensitivity could be considered anomalous when compared to calculated estimates of gage sensitivity. The calculated gage sensitivity to cesium was 0.85 to 1.85 times the nitrogen sensitivity. This calculation was based upon a technique from references 2 and 3 and ionization data from reference 4.

Because of this apparent (and unresolved) anomaly, the observations of reference 1 were repeated with rubidium vapor instead of cesium and are reported herein. In addition, the calculation of reference 1 has been reexamined, revised, and extended to rubidium. Since rubidium is a member of the same periodic group as cesium it would be expected to exhibit properties similar to those of cesium.

The present study deals mainly with commercial gages of the Bayard-Alpert type operated under conditions specified by the manufacturer. Additional measurements were made to determine the effect of grid voltage variation on the gage sensitivity to both rubidium and cesium.

DEFINITION OF IONIZATION GAGE SENSITIVITY

The empirical equation which, defines the ionization gage sensitivity is

$$i_+ = S_A p i_-$$

From this, the ratio

$$r_{AB} \equiv \frac{S_A}{S_B}$$

can be defined so that

$$i_+ = r_{AB} S_B p i_-$$

where

i_+ measured ion current, A

i_- measured ionizing electron current, A

p pressure within gage, torr

S_A, S_B gage sensitivity to gases A and B, respectively, $torr^{-1}$

r_{AB} ratio of gage sensitivities to gases A and B

MEASUREMENTS ON BAYARD-ALPERT GAGE IN RUBIDIUM VAPOR

The apparatus is shown in figures 1 and 2. The procedures and techniques are given in detail in reference 1 and are repeated here in part.

High purity rubidium metal was prepared by reducing rubidium chloride with calcium metal by using the apparatus of figure 1. This rubidium was inserted into and sealed within an ionization gage under high vacuum conditions (10^{-7} to 10^{-9} torr). After the gage was sealed, it was removed from the apparatus and mounted as shown in figure 2.

In the cesium study, the cesium purity was monitored by using the freezing point depression of the cesium sample as an index of the oxygen content. A similar technique was desired here, but the empirical relation for the freezing point depression for oxygen impurities in rubidium was not available in the literature. The relation was therefore calculated by using the Clausius-Clapeyron equation and Raoult's law (ref. 5). The cal-
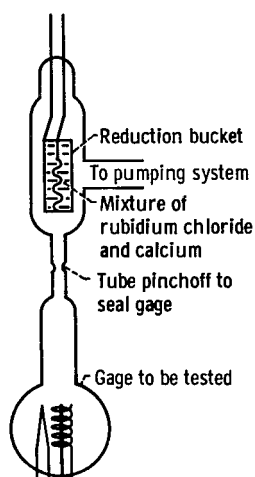
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Figure 1. – Schematic drawing of apparatus for sealing rubidium in gage under vacuum.
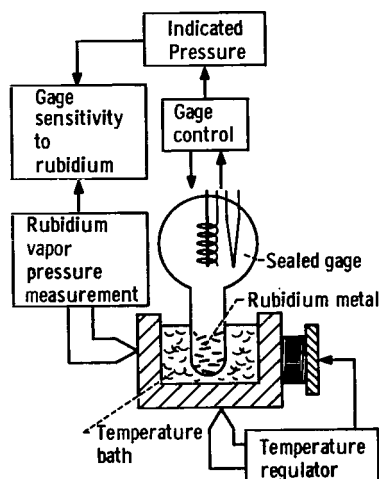

Figure 2. – Schematic drawing of apparatus for determination of gage sensitivity to rubidium.

culated depression was about 1.7 C^o for a content of 1 weight percent of oxygen. The rubidium purity determined by this method was of the order of 99.9 percent.

The vapor pressure information for this study was extrapolated from the tabulated data of reference 6. From comparison with other sources (refs. 7 to 9) the data appears to be accurate to about 20 percent. In addition, extrapolation may introduce further error.

The range of data recorded and the range of background pressures observed in this work differed slightly from those of the previous study (ref. 1). The range of rubidium pressures used for these data was 2×10^{-9} to 5×10^{-7} torr.

The gage background collector current (leakage currents, etc.) on the collector was observed to vary from 1×10^{-9} to 5×10^{-9} ampere. During any test period, however, this current did not vary more than about 1×10^{-10} ampere. Based on a nitrogen gage sensitivity of 0.1 ampere per torr at 10-milliampere electron emission and the observed rubidium gage sensitivity, the collector-current variation contributed an error no greater than 5 percent at the lowest rubidium pressures utilized.

In the course of this investigation, the effects of rubidium on the gage were observed. For the most part, these were found to be very similar to those previously reported for cesium. These effects (ref. 1) were a time constant of the order of hours in response to changes in alkali-metal vapor pressure, photoelectric effects, and gage failure due to metal condensation within the gage envelope.

The photoelectric current from the collector element was at least 10 times smaller than that for cesium. It was difficult to determine the true magnitude of the photoelectric current, since it was masked to a great extent by minor variations in the background-current level. The magnitude of the photoelectric current due to photons emitted from the filament falling on the rubidium-coated collector element was less than 1×10^{-9} ampere (equivalent to an indicated nitrogen pressure of 1×10^{-8} torr).

The leakage currents, a major cause of failure of the gages in the cesium study (ref. 1), were of such a low order that no problems due to interelectrode shorting were encountered. This absence of leakage currents is attributed to the improved shielding of the gage element penetrations through the envelope of the gages used in this study (see fig. 3).
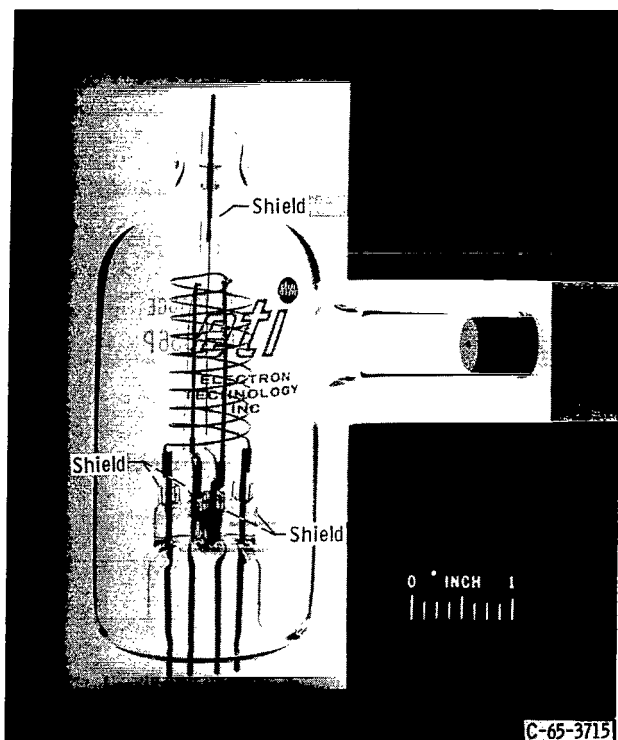
Figure 3. – Bayard-Alpert ionization gage used in determination of gage sensitivity to rubidium. (Note optical glass shields about critical lead penetrations.)
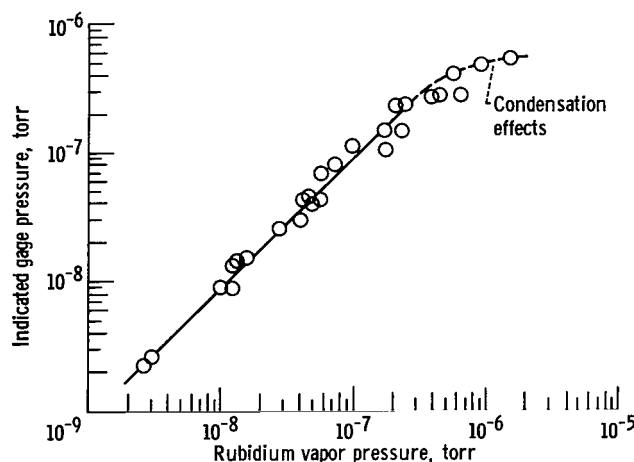

Figure 4. – Data used to determine sensitivity of Bayard-Alpert gage to rubidium vapor. Solid line represents gage sensitivity of 9.1 torr^{-1}.

Even when the rubidium pressure was allowed to rise to the point that excessive rubidium condensation occurred on the envelope, essentially no gage shorting was observed over periods of the order of 1 to 2 hours.

Although the leakage current was eliminated by the modified gage structure, the gage remained inoperative at higher pressure levels. At rubidium pressures of the order of 10^{-6} torr, the gage envelope becomes a sink for condensing rubidium vapor. For this reason, the gage output cannot be used as a pressure indication at pressures above 10^{-6} torr. Because of this condensation, no data above 5×10^{-7} torr of rubidium pressure were used to calculate the gage sensitivity to rubidium vapor. Figure 4 shows the basic data taken to determine gage sensitivity, which in turn demonstrates the condensation effects at higher pressures.

Two Bayard-Alpert gages of the design shown in figure 3 were used to determine gage sensitivity to rubidium vapor. The gages were calibrated for nitrogen against a McLeod gage, and the sensitivities were noted. The gages were operated at a nominal 10-milliampere emission, and the resulting measurements were normalized to the equivalent nitrogen pressure.

All data were recorded and reduced as described in reference 1. The gage sensitivity, as determined from the data of figure 4, was found to have a most probable value of 9.1 times the nitrogen sensitivity of the gage with a probable error in a single observation of 14 percent.
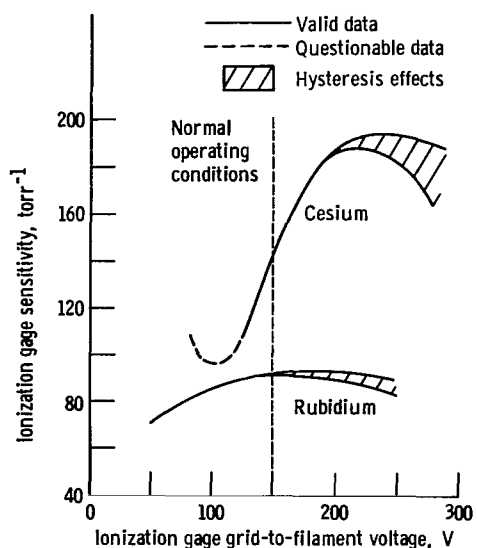
Figure 5. - Observed variation of gage sensitivity to cesium and rubidium with grid-to-filament voltage for Bayard-Alpert gage.

The operating parameters for the gage were

(1) Grid potential (referenced to filament) of +150 volts

(2) Collector potential (referenced to filament) of -30 volts

(3) Envelope temperatures of 60° C near the filament and 35° C remote from the filament

During these experiments, the variation of gage sensitivity with operating voltages was taken as an additional measurement of interest. These measurements were made for both cesium and rubidium. The measurements were made with constant filament-heating current to eliminate problems of temperature variations. The collector current was then corrected for the change in filament emission due to space-charge-limited emission. These measurements are shown in figure 5. The dashed portion of the cesium curve is considered questionable; however, the observed sensitivity reached a minimum at about 100 volts. No appreciable variation in gage sensitivity was noted for collector voltage variations from -20 to -50 volts dc.

DISCUSSION

Consistent results for the experiments with the highly active alkali metals require protracted high-temperature baking of the apparatus, with extreme care being taken to ensure the purity of the alkali-metal sample.

Sufficient purity of the cesium and rubidium samples could not be obtained by using glass ampuls to introduce the metals into the apparatus. Only by reduction of the metal within the apparatus after lengthy baking were consistent results obtained.

Apparently, impurities influence the vapor pressure of the alkali metals greatly, but cause little alteration of the properties of the metal vapor. The main impurity, alkali oxide, would account for only an insignificant portion of the vapor. Because of this, the ionization properties of the vapor are not modified by sample impurities, although the vapor density may be reduced to a significant extent. The result would be reliable relative data, but poor absolute values. For this reason, special care was taken to test for and maintain high purity of the cesium and rubidium used.

In the results shown in figure 5, it is peculiar and perhaps significant that the observed sensitivity curve for cesium as a function of grid voltage reaches a maximum at a

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grid potential nearly twice that of rubidium. An interpretation of these curve shapes would require a detailed analysis of the basic ionization data for the alkali metals and the mode of ionization gage operation.

The cesium sensitivity minimum occurred at a grid potential of about 100 volts, and the sensitivity increase was noted at lower potentials. However, the curve shape and magnitude in the region below a 120-volt grid potential (denoted in fig. 5 as a dashed line) is considered questionable. In this region the results appeared very sensitive to external factors such as ambient light, gage history, and initial test conditions. Both cesium and rubidium showed a hysteresis effect at higher grid potentials, depending upon whether grid potential was increasing or decreasing.

From consideration of the data of figure 5, it would appear that mechanisms other than electron impact ionization of the vapor are included in the measured gage sensitivity of the alkali metals. Possible effects would be photoelectric ionization and ion emission from the grid element due to electron impact.

Because of the possibility of influences from other than the conventional ionization mechanism, the results are considered restricted to the conventional mode of gage operation.

The tubulated ionization gage has an upper pressure limit for reliable operation. This limit is determined by the pressure at which sizable amounts of the alkali metal condense on the gage envelope; for rubidium and cesium, this occurs at about 10^{-6} torr. Examination of the vapor pressure data indicates that a similar limitation for potassium and sodium would occur at about 10^{-8} and 10^{-9} torr, respectively.

Suitable optical shielding of the gage element penetrations through the envelope (and

TABLE I. - CALCULATED AND EXPERIMENTAL

SENSITIVITIES, RELATIVE TO NITROGEN, FOR

THE ALKALI METAL VAPORS

Alkali metal	Relative sensitivity, r		
	Calculated		Experimental[c]
	From published absolute data[a]	From product of absolute and relative data[b]	
Cesium	3.5	14.5	13.7
Rubidium	2.9	8.4	9.1

[a]From ref. 10.
[b]From refs. 11 and 12.
[c]From ref. 1 and present work.

TABLE II. - RATIO OF CESIUM TO RUBIDIUM

GAGE SENSITIVITIES

Source	Ratio of cesium to rubidium sensitivity, S_{Cs}/S_{Rb}
Calculated from data of ref. 10	1.21
Calculated from data of ref. 12	1.74
Experimental	1.50

possibly the use of a nude configuration) appears necessary for reliable operation. However, no permanent gage damage was noted over the course of this study.

The calculation of gage sensitivity was repeated with the most recent data available in the literature (ref. 10). The calculation technique is essentially that given in references 2 and 3. Further, a calculated value for the cesium ionization cross section (ref. 11) was applied to the relative data from reference 12 to calculate gage sensitivity. The results of these calculations are summarized in tables I and II.

The absolute data of reference 10 yield results differing by a factor of 3 to 4 from the observed sensitivities. This difference could be, totally or in part, due to unaccounted-for modes of ionization.

Since the method of sensitivity calculation is considered at best an order of magnitude estimate, the agreement of the experiments with the calculated results based on data from references 11 and 12 is considered very good. It seems significant that there is good agreement among the ratios of cesium and rubidium gage sensitivities given in table II.

The error quoted for the measurement of gage sensitivity reflects the internal consistency of the data in both reference 1 and this study. Errors in the vapor pressure data would introduce a systematic error in the results. The magnitude of this error probably would not exceed 10 percent.

CONCLUSIONS

The following conclusions were drawn from an investigation of the effects of rubidium vapor on Bayard-Alpert ionization gages at pressures less than 1×10^{-6} torr:

1. When Bayard-Alpert ionization gages are operated in rubidium and cesium vapors, there are several effects present which are traceable to the condensable nature of the vapor, such as photoelectric effects and inhibited response to changes in alkali metal vapor pressure.

2. The gage response is further inhibited by condensation resulting at higher pressures. For cesium and rubidium, this upper pressure limit occurs at about 10^{-6} torr.

3. Problems of interelectrode leakage currents can be decreased by adopting a gage configuration which incorporates optical shielding of the electrode penetrations through the gage envelope.

4. The rubidium sensitivity of a Bayard-Alpert ionization gage was determined to be 9.1 times the nitrogen sensitivity, with a probable error of 14 percent.

Lewis Research Center,
  National Aeronautics and Space Administration,
    Cleveland, Ohio, May 26, 1966,
      125-24-03-01-22.

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